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Art. XXXVI.—*Note on Earthquake-Intensity in San Francisco*; by Edward S. Holden, LL.D., Director of the Lick Observatory.

Toward the end of 1887, the Regents of the University of California published a pamphlet prepared by me bearing the title "List of Recorded Earthquakes in California, etc.;" 1887; 8vo, pp. 78. This work contained all the information regarding California earthquakes which I have been able to collect. The information is presented in a popular rather than a scientific form, though the Introduction contains statistics, more or less valuable, relating to the distribution of the shocks by years, months and seasons.

It is the object of the present note to obtain an estimate of the absolute value of the earthquake-intensity developed at San Francisco during our historic period. I am obliged to confine myself to San Francisco, whose records are very complete, owing to the conscientious care of Mr. Thomas Tennant.

With this end in view I have gone over the printed pamphlet and wherever the data were sufficiently exact, I have assigned the intensity of each separate shock on the arbitrary scale of Rossi and Forel, omitting every doubtful case. The later papers of Professor Rockwood already contained this datum. Omitting all doubtful cases, I found 948 shocks at 214 different stations in California which had been so well reported as to allow an intensity on the scale, to be assigned with certainty. In San Francisco, 417 shocks in all have been recorded. Of these, 200 were accurately described.

The Rossi-Forel Scale.

I. Microseismic shock—recorded by a single seismograph, or by seismographs of the same model, but not putting seismographs of different patterns in motion; reported by experienced observers only.

II. Shock recorded by several seismographs of different patterns; reported by a small number of persons at rest.

III. Shock reported by a number of persons at rest; duration or direction noted.

IV. Shock reported by persons in motion; shaking of movable objects, doors and windows, cracking of ceilings.

V. Shock felt generally by every one; furniture shaken; some bells rung.

VI. General awakening of sleepers; general ringing of bells; swinging of chandeliers; stopping of clocks; visible swaying of trees; some persons run out of buildings.

VII. Overturning of loose objects; fall of plaster; striking of church bells; general fright, without damage to buildings.

VIII. Fall of chimneys; cracks in the walls of buildings.

IX. Partial or total destruction of some buildings.

X. Great disasters; overturning of rocks; fissures in the surface of the earth; mountain slides.

Determination of the mechanical equivalent of each degree on the Rossi-Forel scale.

It is necessary to determine the value of each degree on the Rossi-Forel scale in terms of some natural units. This it is impossible to do with exactness, owing to the nature of the subject, and it is somewhat difficult to get results sufficiently exact to be used in practice.

Referring to the Rossi-Forel scale, we find that degrees I, II, III correspond to the *feelings* of the observer—to his sensations. The rest of the scale (IV–X) refers chiefly to the effects of the shock in producing motion upon inanimate matter. The problem is to get some kind of a common unit of a mechanical sort, and to express the various degrees of the scale in terms of this unit. There is no question as to what unit to employ. The researches of the Japanese seismologists have abundantly shown that the destruction of buildings, etc., is proportional to the acceleration produced by the earthquake shock itself in a mass connected with the earth's surface.

The earthquake motion is a wave-motion, and although it is not simple harmonic, it is necessary to assume it to be such to obtain a basis for computation. We assume then a = amplitude of the largest wave; T = period of the largest wave; $V = \frac{2\pi a}{T}$ = velocity of the impulse given by the shock; $I = \frac{V^2}{a} = 4\pi^2 . \frac{a}{T^2}$ = intensity of the shock, defined mechanically

= destructive effect = the maximum acceleration due to the impulse.

It would be logical to express I in fractions of the acceleration due to gravity, *i. e.*, 9810^{mm} per 1^{s}. As these fractions are usually small, it is convenient to give the values of I in terms of millimeters per 1^{s}.

The observations of Ewing, Milne and Sekiya on Japanese earthquakes give for each shock a and T, from which V and I can be computed. Very frequently a description of the effects of the shock on buildings, etc., is given by them, which description is often sufficiently minute to justify the characterization of the shock by one of the degrees of the Rossi-Forel scale.

I have carefully examined all the writings of the three gentlemen named, accessible to me, and after rejecting all doubtful cases, I have found twenty-one shocks ranging in intensity from I to IX, in which the a and T were determined by instruments and in which I could assign the Rossi-Forel intensity with confidence. The following table is the result:

*Equivalents of the degrees of intensity of Earthquake shocks on the Rossi-Forel scale, in terms of the acceleration due to the velocity of the shock itself.**

$$I = \frac{V^2}{a} = \frac{2\pi a}{T^2}$$

Rossi-Forel Scale.	Intensity.			Diff.
I	corresponds to	20^{mm}	per 1^{s}	----
II	"	40	"	(20)
III	"	60	"	(20)
IV	"	80	"	(20)
V	"	110	"	(30)
VI	"	150	"	(40)
VII	"	300	"	(150)
VIII	"	500	"	(200)
IX	"	1200	"	(700)

So far as I know, this is the best determination possible from the meager data now available.

The observations at Berkeley and Mt. Hamilton are especially directed toward obtaining better values of these relations. A few years of observations will determine them, at least for the lighter shocks (I–VI).

* It is interesting to observe the influence of long period in diminishing the destructive effect of a shock of given amplitude. Thus a shock of intensity VIII has $I = \frac{4\pi^2 a}{T^2} = 500^{mm}$ per 1^{s} by observation. If $T = 0{\cdot}1^{s}$, $a = 0{\cdot}1^{mm}$, while if $T = 1^{s}$, $a = 13^{mm}$, and so for other cases.

Absolute intensity of Earthquake action at San Francisco.

417 shocks of all intensities have been recorded at San Francisco in the years 1808–1888. Of these, 200 were described so definitely that their intensities could be assigned on the Rossi-Forel scale with tolerable certainty. This work has been done with great care and is summarized in the following table:

No. of shocks actually recorded at San Francisco (1808–1888) *for which the intensity is known.*

Intensity on Rossi-Forel Scale.	Number of Shocks.
I	8
II	4
III	55
IV	50
V	58
VI	12
VII	4
VIII	7
IX	2
Total,	200

Beside the 200 shocks of known intensity, there are 217 shocks printed in my catalogue. No doubt a great number of the lighter shocks (I, II, III,) are not recorded at all.

Earthquake action is so irregular and lawless, that it is not possible to make any estimate however rough of the number of these lighter shocks. Experience has amply proved that the average intensity of San Francisco shocks is not above IV on the Rossi-Forel scale. The vast majority of our shocks are II and III and the average is certainly below IV. I shall, therefore, assume this fact as a basis for computation.

The 200 shocks of known intensity are evaluated and summed up in the following table:

						Units of Acceleration.
8	shocks of intensity	I	correspond to	8 × 20	=	160
4	" "	II	" "	4 × 40	=	160
55	" "	III	" "	55 × 60	=	3300
50	" "	IV	" "	50 × 80	=	4000
58	" "	V	" "	58 × 110	=	6380
12	" "	VI	" "	12 × 150	=	1800
4	" "	VII	" "	4 × 300	=	1200
7	" "	VIII	" "	7 × 500	=	3500
2	" "	IX	" "	2 × 1200	=	2400
200	recorded shocks of known intensities correspond to					22900 units.

The *average recorded* shock corresponds to I = 114 units or approximately to V on the scale. This simply proves that all, or nearly all, the shocks of intensity V and more severe have been recorded and that the lighter shocks have been neglected.

As has been said 417 shocks in all have been noted (of which only 200 are accurately described). I assume the 217 shocks of unknown intensities to have had between 48 and 49 units of intensity each, or 10460 units in all. This amounts to supposing our average shock to be of intensity IV.

In this way the table will stand:

	Units of Acceleration.
217 shocks of unknown intensity give	10460
200 " " known intensity give	22900
417 shocks recorded (1808–1888) give	33360

The average shock is of intensity IV corresponding to 80 units or to $\frac{1}{123}$d part of the acceleration due to gravity. The total intensity of 33360 units has been experienced in 80 years and corresponds to 3·4 the acceleration due to gravity. That is if all the earthquake force which has been expended in San Francisco during the past 80 years were concentrated so as to act at a single instant, it would be capable of producing an acceleration of 3·4 times that of gravity or about 109 feet per second.

The total earthquake intensity during the 80 years is nearly equal to the intensity of 28 separate shocks as severe as that of 1868, but it has been doled out so gently and gradually that we have scarcely known of it.

On the average 392 units of intensity have been developed during each one of the 80 years (1808–88). This will allow for six shocks of intensity III per year or one every two months. In fact 417 shocks have been recorded in the 960 months.

I believe that my earthquake catalogue as printed and the present note, contain nearly all the precise information which can be extracted from our past records, at this time.

The automatic earthquake registers now in use at the University of California, Berkeley (under the care of Professors Le Conte and Soulé) and at the Lick Observatory, Mount Hamilton, will afford valuable data after a few years.

I am greatly in hopes that the chiefs of the U. S. Geological Survey and of the U. S. Signal Bureau may find it practicable to establish and care for seismometric stations in the state. The cost of such stations is small. I find that the excellent duplex-pendulum instrument of Professor Ewing can be satisfactorily duplicated for $15. The California Electric Works, 35 Market street, San Francisco, is now prepared to furnish such instruments at that price. If a sufficient number of stations can be established in California, it seems to me that we may look forward to the collection of data of real theoretical and of some practical importance within comparatively few years.